MODULE III WORK, POWER, ENERGY

Work is the displacement of an object when a force (push or pull) is applied to it

$W=F.S= FS\cos\theta$,

When the force and displacement are in the same direction**, $\theta=0$ and $W=F.S$**

Work is done when a force produces some kind of motion.

Work is a scalar quantity. In the SI system, the unit of work is Nm or joule (J). 1 J = 1 N x 1 m = 1 kg m/s^2

Types of work

a) Positive work : The work done on an object is said to be positive work when force and displacement are in the same direction.
   Eg:Work done by the gravitational force on a freely falling body is an example of positive work.
b) Negative work : The work done is said to be negative work when force and displacement are in opposite directions.
   Eg: When a body is thrown upwards, the work done by the gravitational force and displacement are opposite and hence, it is an example of negative work.
c) Zero work The work done is said to be zero when force and displacement are perpendicular to each other or when either force or displacement is zero.
   Eg: Work done by gravity when a person walks horizontally with some load on his head is an example of zero work.

Energy is the capacity to do the work.

Types of Energy

a) **Kinetic Energy**: The energy possessed by a body due to its motion is called kinetic energy.
   If m is the mass of the body and v is its velocity, then kinetic energy is given by $K = 1/2\ mv^2$
b) **Potential Energy** : The energy possessed by a body by its position or configuration is called potential energy. F
   The potential energy of the body with mass m. placed at a height h is given by $V = mgh$

Different Forms of Energy

a) **Mechanical Energy** : Mechanical energy is the energy of a system due to its motion, position, or configuration.
   It is the sum of kinetic energy and potential energy of a system.
b) **Heat Energy** : An object possesses heat energy (thermal energy) due to the motion of molecules in it.
   The energy released when we burn wood, coal, oil, or gas is called heat energy. Steam possesses heat energy which is capable of doing work.
c) **Light energy**: Light energy is a form of electromagnetic radiation.

When an excited electron in an atom or a molecule undergoes a transition from a higher energy level to a lower energy level, the difference in energy between the levels is sometimes emitted in the form of light.
Light travels as waves and it is capable of travelling through vacuum.

The plants absorb light energy and convert it into chemical energy (food) through a process called photosynthesis

d) **Sound energy**: Sound energy is produced when an object vibrates.
A sound wave needs a medium to travel through such as air, water, wood, or metal.
Eg: When sound waves fall on the ear membrane, they make it vibrate and we can hear the sound. When a supersonic plane breaks the sound barrier (speed of sound in air), the sound waves produced by it, shake the buildings. Similarly, the thunder of the cloud also shakes buildings. This shows that **sound energy can also do work**.

e) **Electrical energy:** The energy produced by the movement of electrons is called electric energy.

f) **Magnetic energy** : Magnetism is described by magnetic fields which are produced either by magnetic materials (permanent magnets) or by electric currents.
Energy stored in a magnetic field is called magnetic energy.
Magnetic energy is used in electromagnets, electric motors, electric generators, microphones, television tubes, telephones, etc.

g) **Chemical Energy** : Chemical energy is defined as the energy stored in the bonds between atoms or molecules in a compound. When this compound undergoes a chemical reaction, the chemical energy stored in the bonds will be released in the form of heat.
The energy possessed by the fuels like coal, oil, gas, etc. is chemical energy. The chemical energy of diesel, petrol, or CNG is capable of moving vehicles. The food that we consume, possesses chemical energy which is utilized by our body to do work.

h) **Nuclear energy** : The binding energy of nucleons (neutrons and protons) in the nucleus is called nuclear energy. The nucleus in an atom has an enormous amount of energy which holds the proton and neutrons together.

When a heavy nucleus splits into light nuclei (Nucler fission) or two light nuclei combine to form one nucleus(Nuclear Fusion) , it releases energy

In nuclear power stations, nuclear energy is used to generate electric energy (Fission). In the case of an atom bomb or hydrogen bomb, nuclear energy is used for destructive purposes(Fusion).

i) **Solar Energy** : Solar energy is radiant light and heat from the Sun. Solar energy is created by nuclear fusion that takes place in the sun.
The primary source of all kinds of energy on Earth is solar energy. Solar energy provides wind energy, tidal energy, and energy of sea waves. Solar energy causes the evaporation of water, which in turn leads to the water cycle.
The phenomenon of photosynthesis is not possible without solar energy. It is necessary for life on Earth and can be harvested for human use in many ways. Solar

cells absorb sunlight and convert solar energy into electrical energy. Solar cooker, Solar water heater, etc. utilizes heat energy present in the solar radiation.

Law Conservation of Energy

The Law of conservation of energy states that energy can neither be created nor be destroyed, but can be converted from one form to another.

In other words**, the total energy of an isolated system remains always constant.**

Prove that, for a freely falling body, the total energy is the sum of its kinetic energy and potential energy

Consider a body of mass m, initially placed at height h above the ground level as shown in Figure. .Let the body is allowed to fall freely from its initial position A. **In the case of a freely falling body, the total energy is the sum of its kinetic energy and potential energy**.

As the body moves under gravity, its velocity and hence, kinetic energy increases. But at the same time, the height of the body from the ground decreases, and hence, the potential energy decreases.

At Point A

Velocity at point A, v = 0, then

Kinetic energy at point A,

$$K_A = \frac{1}{2} m v_A^2 = 0$$

The potential energy at point A, $V_A = mgh$

Total energy at point A, $\boldsymbol{E_A = K_A + V_A = 0 + mgh = mgh}$ ------------ (1)

At Point B

B be a point at a distance x from point A.

The velocity at point B, v_B can be calculated using the equation, $v^2 = u^2 + 2as$.

$v = v_B$; $u = v_A = 0$; $a = g$; $s = x$; $v_B^2 = 2gh$

Kinetic energy at point B,

$$K_B = \frac{1}{2} m v_B^2 = \frac{1}{2} m 2gx = mgx$$

The potential energy at point B, $V_B = m(h - x)$

Total energy at point B, $\boldsymbol{E_B = K_B + V_B}$, $= mgx + m(h - x) = mgh$ ---------- (2)

At point C

C be a point on the ground.

The velocity at point C, v^2 can be calculated using the equation, $v^2 = u^2 + 2as$.

$v = v_c$; $u = v_A = 0$; $a = g$; $s = h$; $v^2 = 2gh$

Kinetic energy at point C,

$$K_C = \frac{1}{2} m v_c^2 = \frac{1}{2} m \times 2gh = mgh$$

The potential energy at point A, $V_C = 0$

Total energy at point A, $\boldsymbol{E_C = K_C + V_C = mgh + 0 = mgh}$ ---------- (3)

It is clear from equations (1), (2), and (3) that $E_A = E_B = E_C$.

Hence total energy of the freely falling body remains constant at every point on its path.

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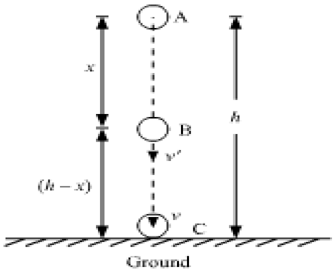


Power is defined as the rate at which work is done. In other words, power is the work done in unit time. If W is the work done in a time t, the average power is given by

$$Power = work \times time$$

But work done is defined as the product of force and displacement.

$$W = FS \therefore P = FS\ t$$

But the velocity of the body is given by $v = S\ t$ $\therefore P = F$v

1 kilowatt (kW) = 10^3 watt
1 megawatt (MW) = 10^6 watt
1 Horsepower (Hp) = 746 watt

FRICTION

The property by which an opposing force is generated between two surfaces in contact with bodies in relative motion is called friction.

Causes of friction

When two bodies come into contact, due to the irregularities of the surfaces, the area of contact is less than the actual area of the surfaces. This causes very high pressure at the point of contact. The high pressure causes deformation of the surface of the material and eventually increases the resistance to motion.

Types of friction

a) **Static friction(f_s):** The frictional force existing between two surfaces when they remains at rest until the force of static friction is overcome.
 The maximum value of static friction before the body starts moving over a surface is called **limiting friction (f_{max}).**

$$f_{max} \propto N, \qquad f_{max} = \mu_s N$$

The constant of proportionality μ_s is called the coefficient of static friction

$$f_s \leq f_{max} = \mu_s N$$

b) **Kinetic or dynamic friction** is the opposing force that comes into play when one body is moving over the surface of another body.

$$f_k \propto N$$

$$f_{max} = \mu_k N$$

Where μ_k is called the coefficient of kinetic friction.
Kinetic friction is classified into two types
a) **Sliding friction**: The frictional force that comes into play when one body is actually sliding over the surface of the other body is called sliding friction.
b)**Rolling friction**: The frictional force that plays when one body is actually rolling over the surface of the other body is called rolling friction.
 Rolling friction is less than sliding friction.

c) **Laws of friction**

1. The Force of friction depends on the nature of surfaces in contact.
2. Friction is independent of the area of contact as long as the normal force is the same.

3. The maximum force of static friction is directly proportional to the normal force.
4. Kinetic friction is directly proportional to the normal force acting between the two bodies in relative motion.
5. The direction of kinetic friction on a body is opposite to the velocity of the body.
6. The magnitude of kinetic friction is independent of the velocity of motion of the body.
7. The coefficient of kinetic friction is always less than the coefficient of static friction for the same pair of surfaces.

d) Advantages of friction

i. It is the friction between the ground and the feet that help us to walk
ii. It helps us to hold things.
iii. The friction between tyres and the road helps us to stop the vehicle when the brake is applied.
iv. Nails and screws join two surfaces due to the force of friction.
v. Without friction, it is impossible to climb a tree or fix a nail on the wall.

e)Disadvantages of friction

i. Friction slows down the motion of moving objects.
ii. Friction produces unnecessary heat leading to the wastage of energy.
iii. It decreases the efficiency of the machines.
iv. It causes wear and tear for the moving parts of the machines.
v. Friction sometimes creates fire accidents like forest fires

Methods to reduce friction

a) Lubrication

When the gap between two surfaces is filled with oil or grease, irregularities become filled with this and the friction reduces. This process is called lubrication and the substance used for this are called lubricants.

Eg: mineral oil, vegetable oil, and colloidal thin oil, grease is used.
For light machinery like watches, sewing machines, etc., thin oil is used
In very heavy machinery, solid lubricants like graphite are used.

b) Polishing of rough surfaces
c) Use of ball bearings in moving parts

HEAT

The energy transferred from one body to another without any mechanical work involved is called heat.

The temperature of a substance is the degree of hotness or coldness on some chosen scale.

Heat energy and temperature are different. When heat energy is given to a substance its temperature may increase and when heat energy is taken from the substance its temperature may fall.

In the CGS system, the unit of heat is calorie. The SI unit of heat is Joule.

One calorie is equal to 4.2 J

Temperature scales

The major temperature scales used are the Celsius, Fahrenheit, and Kelvin scales

The equation to convert between Celsius and Kelvin temperature scales is given by

$K = C + 273$

The equation to convert between Celsius and Fahrenheit temperature scales is given by

$F = 1.8\,C + 32$

Thermometers

A thermometer is a device used to measure temperature.

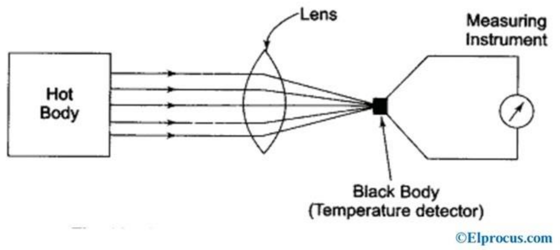
The science of measuring temperature is known as thermometry.

Any physical property that depends on temperature, and whose response to temperature is reproducible, can be used as the basis of a thermometer.

Mercury Thermometer

In a mercury thermometer, a glass tube is filled with mercury and a standard temperature scale is marked on the tube. With changes in temperature, the mercury expands and contracts, and the temperature can be read from the scale. Mercury thermometers can be used to determine body, liquid, and vapor temperature. Mercury thermometers are used in households, laboratory experiments, and industrial applications.

Pyrometer



A pyrometer is **an instrument that measures temperature remotely**, i.e. by measuring radiation from the object, without having to be in contact. I**t measures the object's temperature by sensing the heat/radiation emitted from the object without making contact with the object**. It records the temperature level depending upon the intensity of radiation emitted.

The pyrometer has two basic components like optical system and detectors that are used to measure the surface temperature of the object.

When any object is taken whose surface temperature is to be measured with the pyrometer, the optical system(lens) will capture the energy emitted from the object. Then the radiation is sent to the detector, which is very sensitive to the waves of radiation. The output of the detector refers to the temperature level of the object due to the radiation.

Modes of heat transfer

There are three modes of heat transfer namely **conduction, convection, and radiation.**

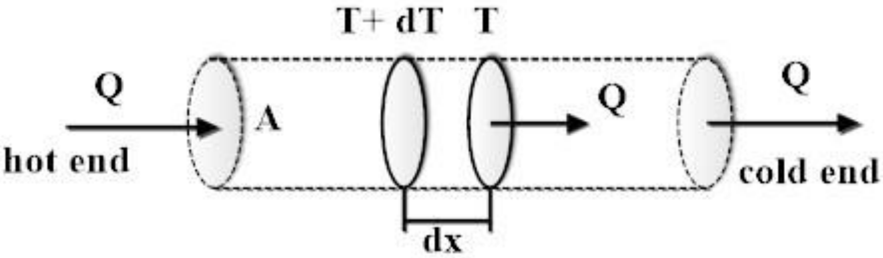
(a) Conduction :

Heat conduction involves **the transfer of heat from one molecule to an adjacent molecule as an inelastic collision** in the case of fluids, **as oscillations** in solid nonconductors of electricity, and **as motions of electrons** in conducting solids such as metals.

Metals are good conductors whereas gases and nonmetals are poor conductors. Aluminium, gold, copper, silver are examples of conductors. Silver is the best conductor of heat.
Asbestos, rubber, glass paper, etc. are examples of insulators.

The ability of a material to conduct heat is measured by a quantity called **thermal conductivity of the material.**

Consider a metallic rod of the area of cross-section A.



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The quantity of heat flowing through the rod depends on its area of cross-section, temperature gradient $\frac{dT}{dx}$ and time (t) for which heat flows.

It can be mathematically expressed as $Q\alpha\, A\frac{dT}{dx}t$ t

Or $Q = \lambda\, A\frac{dT}{dx}t$

Where λ is called thermal conductivity of the material.

Hence $\lambda = \frac{Q}{A(\frac{dT}{dx})t}$. The SI unit of λ is $Wm^{-1}\ s^{-1}$

Some practical applications of thermal conductivity

j) Cooking utensils are made of metals and their handles are made of wood. This is because metals are good conductors of heat, while wood is a bad conductor of heat.
ii) When we take a metal ice tray and a package of frozen food from the freezer of the refrigerator, the metal tray feels colder than the package. This is because metal is a good conductor of heat and it removes heat from our hands much faster.
iii) Houses made of hollow brick walls are cooler than concrete walls.
iv) During winter birds swell their feathers. In doing so the air trapped between the feathers prevent the loss of heat from their body. This is because air is a poor conductor of heat.
v.) Ice is packed in sawdust or gunny bags. This is because air trapped in them prevents loss of heat and so ice does not melt. Air is a poor conductor of heat.

b) Convection:

Heat transfer by convection is also due to molecular motion. However, **during convection molecules are also transported**, or moved, due to fluid motion

The rate at which heat is transferred from the surface of the fluid is given by the relation

$\frac{Q}{t} = hA\Delta T$ where A is the surface area of fluid, ΔT is the temperature difference between the fluid at the upper and lower surfaces and h is a constant called convection coefficient.

The value of h depends on the shape of the surface and whether the surface is horizontal or vertical

Convection is classified as natural convection and forced convection.

Natural convection is a process in which fluid motion is generated due to differences in densities and temperature gradient.

Forced convection is a convection process in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.).

The main mechanism **of heat transfer inside a human body is forced convection**. The heart serves as the pump and blood as the circulating fluid. The heat from our body is lost to the atmosphere through all three processes conduction, convection, and radiation. But our blood circulation system transports just the required amount of heat to maintain a constant body temperature.

c) Radiation:

In Radiation heat transfer can occur in a vacuum

The type of radiation associated with the transfer of heat is often known as **infrared radiation.** This is because the wavelength range of thermal radiation is from 800 nm to 400 μm, which belongs to the infrared region.

In the radiation process, a hot body emits thermal radiation in all directions. Emitted radiation travels through space and falls on another body. The heat from the sun reaches the earth by radiation.

Some basic properties of thermal radiations are given below.

a) They travel in straight lines with the speed of light ($3x10^8$m/s)
b) A material medium is not necessary for propagation.
c) They do not heat the medium through which they are travelling.
d) They can be reflected and refracted just as light.
e) They also exhibit the phenomena like interference, diffraction, and polarization.
f) Thermal radiations have longer wavelengths than visible light.